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Communication

Globular Clusters and the Halos of Dwarf Galaxies

Søren S. Larsen

Department of Astrophysics/IMAPP, Radboud University, P.O. box 9010, 6500 GL Nijmegen, The Netherlands; s.larsen@astro.ru.nl

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Abstract: Many dwarf galaxies have disproportionately rich globular cluster (GC) systems for their luminosities. Moreover, the GCs tend to be preferentially associated with the most metal-poor stellar populations in their parent galaxies, making them attractive tracers of the halos of dwarf (and larger) galaxies. In this contribution, I briefly discuss some constraints on cluster disruption obtained from studies of metal-poor GCs in dwarf galaxies. I then discuss our recent work on detailed abundance analysis from integrated-light spectroscopy of GCs in Local Group dwarf galaxies.

Keywords: galaxies: abundances; galaxies: star clusters; globular clusters: general

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1. Introduction

In most galaxies, stellar halos account for only a small fraction of all stars. Their low surface brightnesses make them challenging to study in integrated light, and even in more nearby galaxies, where individual stars can still be resolved, samples of old stellar population tracers (such as red giants) are often dominated by the more metal-rich populations. However, the number of globular clusters (GCs) per halo star usually increases steeply with decreasing metallicity, making GCs attractive tracers of the (metal-poor) halo populations in their parent galaxies. Furthermore, the GC specific frequency increases significantly towards low galaxy masses/luminosities [1–3]—a trend that mirrors the trend of overall mass-to-light ratio vs. galaxy mass. Indeed, it has been noted that GCs constitute a remarkably constant fraction of the total mass of galaxies (about 6×10^{-5}, [1,2,4]). Whether this implies a universal *formation* efficiency of GCs relative to total galaxy mass or differences in GC *disruption* efficiency [5] remains an open question. However, as will be discussed below, the fraction of metal-poor stars that belong to GCs can be so high in some dwarf galaxies that this puts useful constraints on the role of cluster disruption.

In this contribution, I first discuss how GCs can be used to put constraints on the role of cluster disruption/dissolution in dwarf galaxies (Section 2). In Section 3, I then proceed to discuss our recent results on chemical abundances of GCs from analysis of their integrated light.

2. Globular Clusters in Dwarf Galaxies: Implications for Cluster Disruption

As noted by [1], some dwarf galaxies can reach specific frequencies $S_N > 100$. Of course, it should be kept in mind that small number statistics can cause large fluctuations in the specific frequencies of dwarfs. However, even if this is taken into account (by looking at average S_N values), there is still a clear trend of increasing S_N with decreasing host galaxy M_V, reaching $\langle S_N \rangle \approx 20$ for galaxies with $-12 < M_V < -10$ [1].

The Fornax dwarf spheroidal galaxy has five GCs and an absolute magnitude $M_V = -13.2$, yielding a specific frequency of $S_N = 26$ [6]. Four of these five GCs have $[\mathrm{Fe/H}] < -2$, while this is true for only 5% of the field stars. It has been estimated that about 20–25% of the metal-poor stars (those with $[\mathrm{Fe/H}] < -2$) are currently members of GCs [6]. While this is a much higher fraction than in the Milky Way halo (where about 2% of the stellar mass is in GCs), this high fraction may not be particularly unusual among dwarf galaxies; the single GC in the Wolf–Lundmark–Melotte (WLM) dwarf contributes a similar fraction of the metal-poor stars, and the ratio may be even higher in the IKN dwarf galaxy in the Ursa Major group [7].

These high GC/field ratios constrain the fractions of stars that could have been lost from the globular clusters, and thus scenarios for dynamical evolution. In particular, most scenarios for the origin of *multiple populations* in GCs need to invoke the loss of a large number of "pristine" stars (i.e., stars with composition similar to that observed in the field) from the clusters in order to explain the observed large fractions of stars with anomalous abundance patterns. Typically, the loss of more than 90% of the initial cluster mass is required [8–10], which is in clear tension with the large present-day GC/field star ratios in dwarf galaxies like Fornax. However, there are also more general implications for cluster disruption. The mass functions of young cluster systems are generally well described by Schechter-like functions, $dN/dM \propto M^{-2}\exp(-M/M_c)$; i.e., they are approximately power-laws with an exponent of about -2 at low masses and exponentially truncated above some cut-off mass, M_c. This differs from the mass function of old GCs, which is roughly flat below a mass of $\sim 10^5 M_\odot$. However, the mass function of old GCs can be well described by an "evolved" version of the Schechter function, where clusters lose mass at an (average) constant rate of about $\Delta M = 2.5 \times 10^5 M_\odot$ per Hubble time. Clusters with (initial) masses below this value have thus dissolved completely, whereas clusters with present-day masses less than ΔM all had initial masses in a relatively small range above ΔM, leading to the flat present-day MF at low masses. In this simple view, the mass lost to the field from dissolving clusters would again exceed the current mass contained within surviving clusters by factors of >10 [11–14].

It is possible that the initial mass distribution of globular clusters was more top-heavy than observed in young cluster systems. In the extreme case, it might even be that the GCs we observe today in dwarf galaxies like Fornax are the only ones that ever formed—an idea that may find some support in observations of dwarf irregular galaxies that are currently experiencing—or have recently undergone—starburst activity. Examples are NGC 1569 and NGC 1705, both of which are dominated by 1–2 massive ($(5-10) \times 10^5 M_\odot$) young star clusters [15].

3. Chemical Abundances of GCs in Dwarf Galaxies

The preponderance of metal-poor GCs makes them attractive tracers of the metal-poor stellar populations in dwarf galaxies. Within the Local Group, high-quality spectra of the brighter GCs can be obtained in a few hours of 8–10 m telescope time, from which detailed chemical abundances can be measured. The next generation of 30–40 m telescopes will be able to push this type of measurements well beyond the Local Group.

Traditionally, measurements of metallicities and chemical abundances from integrated light have relied on techniques developed for relatively low-resolution spectra such as the Lick/IDS system of absorption line indices. However, with velocity dispersions of only a few km/s, integrated-light spectroscopy of GCs can benefit from much higher spectral resolution, which potentially makes it possible to employ techniques that are more closely related to those used in classical stellar abundance analysis. The challenge, of course, is that one still needs to model contributions from a mix of different types of stars within the cluster. We have recently tested our method developed for this type of analysis on a sample of seven Milky Way globular clusters, spanning a metallicity range from $[\mathrm{Fe/H}] \simeq -2.3$ (M15, M30) to $[\mathrm{Fe/H}] \simeq -0.5$ (NGC 6388). In essence, we compute "simple stellar population" (SSP) models at very high spectral resolution, based on theoretical model spectra for which we can adjust the abundances of individual elements until the best match to the observed spectra is obtained. The model atmospheres and synthetic spectra are mostly computed with the ATLAS9 and SYNTHE codes [16,17], except for the coolest giants for which we use MARCS atmospheres and the TurboSpectrum code [18–20]. Figure 1 shows example fits to three integrated-light GC spectra around the Na I doublets at 5683/5688 Å (left) and 6154/6161 Å (right). While the 6154/6161 Å lines are blended with Ca I and Sc I lines, we found that our full spectral fitting technique gave very consistent Na abundances for the two doublets, with an average difference of only 0.02 dex for the two sets of lines. From this type of fit, we can typically measure the abundances of a wide range of light, α-, Fe-peak, and heavy elements with an accuracy of $\sim$0.1 dex (based on comparison with measurements of individual stars) [21].

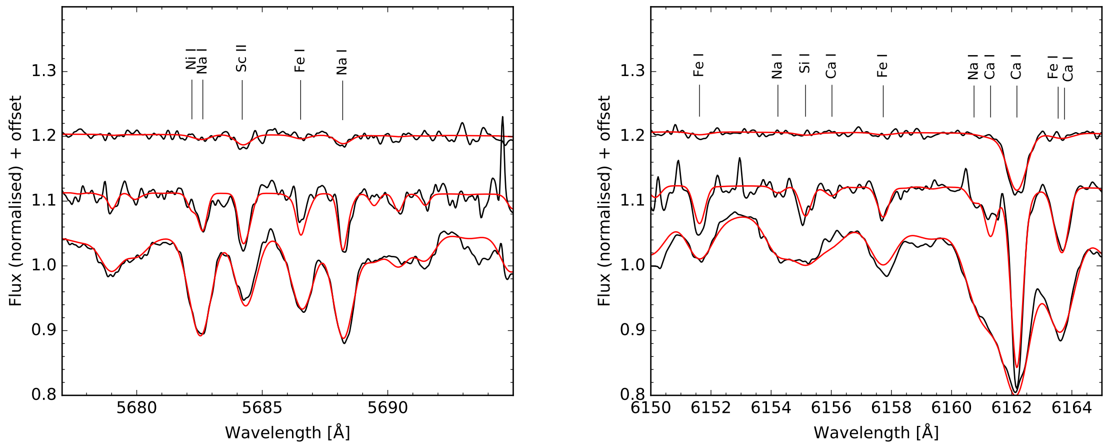

Figure 1. Fits to integrated-light spectra of the Galactic GCs NGC 7078 (**top**), NGC 6254 (centre), and NGC 6388 (**bottom**) for the regions near the Na I doublets at 5683/5688 Å (**left**) and 6154/6161 Å (**right**). From this type of fit, we can measure the abundances of many individual elements (e.g., Fe, Na, Mg, Ca, Sc, Ti, Cr, Mn, and Ba). From [21]. Credit: Søren S. Larsen, A&A, 601, A96, 2017, reproduced with permission ©ESO.

We have initiated an effort to carry out detailed chemical abundance analysis of GCs in dwarf galaxies in the Local Group, using the UVES and HIRES spectrographs on the VLT and Keck, respectively. Our published data for GCs in the Fornax and WLM dwarf galaxies [7,22], as well as recently obtained observations of GCs in NGC 147 and NGC 6822, indicate that the most metal-poor GCs in these dwarf galaxies (those with [Fe/H] < -1.5) generally display abundance patterns similar to those in GCs in the Milky Way, with the α-elements (Ca, Ti) being enhanced by about 0.3 dex relative to Solar-scaled composition. Na is typically enhanced compared to the composition seen in Milky Way field stars, but the integrated-light [Na/Fe] ratios are similar to the average values for individual stars in Milky Way GCs, thus providing a strong hint that multiple populations (with about half of the stars being Na-rich) are also present in these extragalactic GCs. In a few clusters, magnesium is depleted relative to other α-elements, which may indicate the presence of the Mg–Al anticorrelation. A similar effect has also been noted by other studies (e.g., in M31 GCs [23,24]). Of the GCs in dwarf galaxies that we have observed so far, only two (Fornax 4 and NGC 6822-SC7) have [Fe/H] > -1.5. Interestingly, these clusters both have approximately Solar-scaled α-element abundances, in agreement with the trends seen in field stars in dwarf galaxies [25]. Cluster SC7 also exhibits a number of other peculiarities, including a significantly sub-Solar [Sc/Fe] ratio and low [Ni/Fe] and [Na/Fe] ratios [26]—indeed, its detailed chemical abundance patterns closely match those in the galactic GC Ruprecht 106, for which an accretion origin has been suggested [27]. A few GCs in the M31 with similar abundance patterns may likewise be accreted [23,24]. This illustrates that detailed chemical abundance analysis of GCs may provide important clues to the enrichment and accretion histories of galactic halos. Finally, we note that efforts are also on-going to extend this type of analysis to younger star clusters in star-forming galaxies beyond the Local Group, where they provide a welcome alternative to more traditional methods such as measurements of strong emission lines from H II regions [28].

4. Conclusions

Globular clusters were evidently an important site of star formation in the early Universe, and this is particularly true for some dwarf galaxies. The high specific frequencies of GCs relative to metal-poor stars in galaxies such as the Fornax dSph constrain the amount of mass that could have been lost from individual clusters and from the cluster population as a whole.

With efficient and highly multiplexed spectrographs on future 30–40 m telescopes, it will be possible to apply the techniques developed for integrated-light abundance analysis to GC systems well beyond the Local Group. In combination with constraints on stellar populations from resolved imaging of individual stars, this will likely lead to a much more detailed picture of the assembly histories of galactic halos.

Conflicts of Interest: The author declares no conflict of interest.

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